Comparison of WinSLAMM Modeled Results with Monitored Bioinfiltration Data during Kansas City Green Infrastructure Demonstration Project

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Stormwater Infiltration Controls Included in WinSLAMM

- Bioretention/biofiltration areas
- Rain gardens
- Porous pavement
- Grass swales and grass filters
- Infiltration basins
- Infiltration trenches
- Green (and blue) roofs
- Disconnections of paved areas and roofs from the drainage system
- Also considers evapotranspiration and stormwater beneficial uses

“SEA” (Street Edge Alternative) Street, Seattle, WA
Kansas City’s CSO Challenge

- Combined sewer area: 58 mi²
- Fully developed
- Rainfall: 37 in./yr
- 36 sewer overflows/yr by rain > 0.6 in; reduce frequency by 65%.
- 6.4 billion gal overflow/yr, reduce to 1.4 billion gal/yr
- Aging wastewater infrastructure
- Sewer backups
- Poor receiving-water quality

KC’s Modeling Connections

- SUSTAIN-SWMM
  - Individual LID
  - Drainage (Transport)
  - Multi-scale
  - Subarea Optimization
- KCMO XP-SWMM
  - Drainage (Transport)
  - Design Objectives
- WinSLAMM
  - Land Surface Characterization
  - Drainage (Transport)
  - Design Options
  - Stormwater Beneficial Uses
  - Multi-scale
- 744 acres
- Distributed storage with “green infrastructure” vs. storage tanks
- Need 3 Mgal storage
- Goal: < 6 CSOs/yr

Kansas City’s Revised Middle Blue River Plan with Distributed Storage and Green Infrastructure
Surveys were conducted for each house and lot in the study area. This information was used with the GIS data and WinSLAMM to determine the sources of the runoff during different rain conditions.
### Major Land Use Components in Residential Portion of Study Area (% of area and % of total annual flow contributions)

<table>
<thead>
<tr>
<th>Component</th>
<th>Roofs</th>
<th>Drive-ways</th>
<th>Sidewalks</th>
<th>Parking</th>
<th>Streets</th>
<th>Landscaped</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly connected</td>
<td>2 (6)</td>
<td>4 (9)</td>
<td>1 (3)</td>
<td>2 (5)</td>
<td>9 (21)</td>
<td>18 (44)</td>
<td></td>
</tr>
<tr>
<td>Disconnected</td>
<td>11 (7)</td>
<td>4 (3)</td>
<td>1 (1)</td>
<td></td>
<td></td>
<td>16 (11)</td>
<td></td>
</tr>
<tr>
<td>Landscaped</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>66 (45)</td>
<td>66 (45)</td>
</tr>
<tr>
<td>Total area</td>
<td>13 (13)</td>
<td>8 (12)</td>
<td>2 (4)</td>
<td>2 (5)</td>
<td>9 (21)</td>
<td>66 (45)</td>
<td>100</td>
</tr>
</tbody>
</table>

Based on KCMO GIS mapping and detailed site surveys, along with WinSLAMM calculations.
Sources of Flows in Test Watershed (no stormwater controls)

Continuous Simulations using Kansas City 1972 to 1999 Rain Series to Evaluate Roof Runoff Controls in Combined Sewer Area
September 2, 2008 to October 12, 2012 Rains Monitored in the Kansas City Green Infrastructure Test Area

This plot shows the time-averaged infiltration rates based on the individual incremental values. The surface infiltration rates are less than 25 mm/hr for rains about 2 hrs long and longer.

Additional site measurements and deep soil profiles have indicated that infiltration rates may be low for most of the area during the large and long-duration critical events for overflows.
Example Water Level in Influent Flume and Water Stage Recordings in Biofilter used for Calculating Infiltration Rates during Rains

Measured Biofilter Infiltration Rates During Actual Rains, Separated into Three Categories
Observed vs. Modeled Flows during Final Baseline Conditions

Legend:
- Call out values
- Street network
- Curbed extension with bioswales
- Curbed extension with rain gardens
- Permeable sidewalk
- Shallow bioswale
- Bioswale
- Curb cut
- Rain garden
Example micro flow and drainage area analysis for a set of stormwater controls in the test area, examining both direct runoff area to biofilters and overflows from upgradient biofilters.
### Characteristics of Areas Draining to Stormwater Controls vs. Areas without Controls

<table>
<thead>
<tr>
<th>Land Component</th>
<th>Area in subwatersheds with no devices</th>
<th>Area in subwatersheds with stormwater control devices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (acres)</td>
<td>Percent of subarea</td>
</tr>
<tr>
<td>Impervious, directly connected</td>
<td>8.09</td>
<td>17.7</td>
</tr>
<tr>
<td>Impervious, draining to pervious areas</td>
<td>9.04</td>
<td>19.7</td>
</tr>
<tr>
<td>Pervious areas</td>
<td>28.70</td>
<td>62.6</td>
</tr>
<tr>
<td>Total area:</td>
<td>45.83</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Examples from “95%” plans prepared by URS for project streets. Plans reviewed and modeled by project team, and construction completed in Summer 2012. Initial monitoring until October 2012, extended monitoring thru Spring 2013.
### Summary of Constructed Stormwater Controls in Test Area

<table>
<thead>
<tr>
<th>Design plan component</th>
<th>Number of this type of stormwater control units in 100 acre test (pilot) area</th>
<th>Device as a % of the drainage area</th>
<th>Average drainage area for each unit (ac)</th>
<th>Total area treated by these devices (ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioretention</td>
<td>24 (no curb extensions)</td>
<td>1.6</td>
<td>0.40</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>28 (with curb extension)</td>
<td>1.5</td>
<td>0.40</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td>5 (shallow)</td>
<td>1.6</td>
<td>0.40</td>
<td>2.0</td>
</tr>
<tr>
<td>Bioswale</td>
<td>1 (vegetated swale)</td>
<td>8.9</td>
<td>0.50</td>
<td>0.5</td>
</tr>
<tr>
<td>Cascade</td>
<td>5 (terraced bioretention cells in series)</td>
<td>1.9</td>
<td>0.40</td>
<td>2.0</td>
</tr>
<tr>
<td>Porous sidewalk or pavement</td>
<td>18 (with underdrains)</td>
<td>100.0</td>
<td>0.015</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>5 (with underground storage cubes)</td>
<td>99.9</td>
<td>0.015</td>
<td>0.1</td>
</tr>
<tr>
<td>Rain garden</td>
<td>64 (no curb extensions)</td>
<td>2.8</td>
<td>0.40</td>
<td>25.6</td>
</tr>
<tr>
<td></td>
<td>8 (with curb extension)</td>
<td>1.5</td>
<td>0.40</td>
<td>3.2</td>
</tr>
</tbody>
</table>

### Test to Control Area Runoff Flow Ratios during Different Monitoring Periods

- **Study Period**: 1: Initial baseline; 2: After re-lining (new baseline) 3: During construction; 4: After construction
Test and Control Watershed Flow Comparisons

<table>
<thead>
<tr>
<th>Monitoring Period</th>
<th>Average test (pilot) to control area runoff volume ratio</th>
<th>% change compared to initial baseline (and p from Wilcoxon Rank-Sum test)</th>
<th>% change compared to final baseline (after re-lining) (and p from Wilcoxon Rank-Sum test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial baseline</td>
<td>1.06</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>After re-lining (final baseline)</td>
<td>1.53</td>
<td>44% increase (p=0.20)</td>
<td>n/a</td>
</tr>
<tr>
<td>During construction</td>
<td>1.02</td>
<td>4% decrease (p=0.94)</td>
<td>33% decrease (p=0.26)</td>
</tr>
<tr>
<td>After construction (after April 1, 2012)</td>
<td>0.46</td>
<td>55% decrease (p=0.006)*</td>
<td>70% decrease (p=0.004)*</td>
</tr>
</tbody>
</table>

Decreasing Test Area Flows Compared to Control Area Flows During and After Construction
Observed and Modeled Flows in the Test Watershed after Construction of Stormwater Controls

One of the Kansas City rain gardens being monitored (zero surface discharges during two years of monitoring; this rain garden is 20% of roof drainage area)
Percentage Reductions of Annual Runoff Flows with Rain Gardens

Effects of Underdrains in Biofilters on Annual Runoff Reductions (0.5 in/hr subsurface soil infiltration rates)
Clogging Potential for Biofilters in the Kansas City Test Area

[Graph showing potential years to clogging vs. biofilter as a percentage of residential drainage area.]

1324 76th St. monitoring location, biofilter and adjacent porous concrete sidewalk
Design drawings for 1324 76th St biofilter.

Other Stormwater Controls in Test Area
Conclusions

- There are a large number of infiltration-based stormwater controls that can be applied to a variety of land uses to reduce the volume and rates of stormwater discharged to combined sewers.
- Beneficial uses of stormwater can also be a useful tool to reduce these discharges, while still conserving important resources.
- Continuous WinSLAMM simulations can calculate the benefits of these controls in many combinations for an area.